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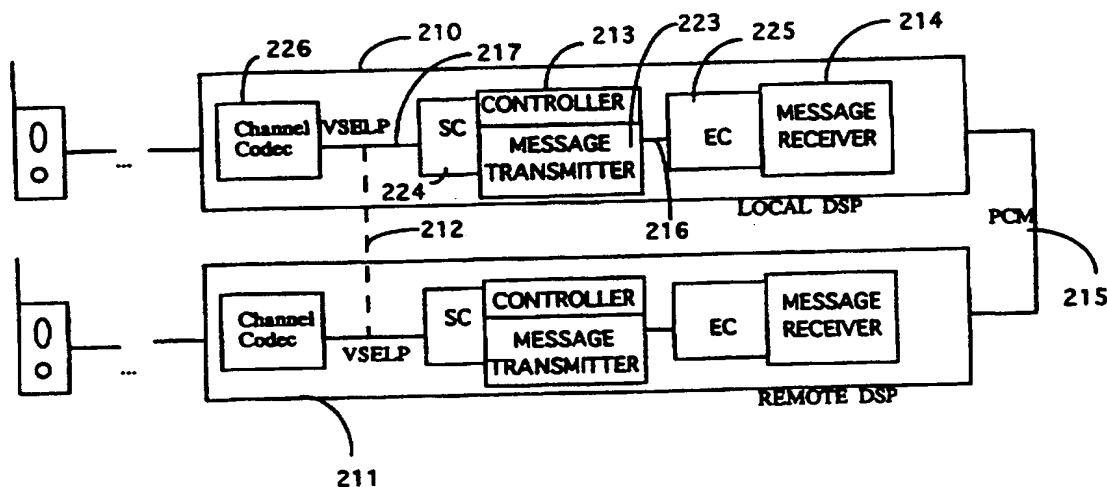
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(57) Abstract

In a TDMA mobile-to-mobile connection, the end-to-end audio signal quality as well as system performance can be improved by providing digital signal processors the capability to automatically switch configuration such that each digital signal processor in a mobile-to-mobile communication connection can automatically identify a TDMA mobile-to-mobile connection and bypass the speech encoding and decoding processes within the digital signal processors. The two digital signal processors are virtually connected at the channel codecs.

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SYSTEM FOR TDMA MOBILE-TO-MOBILE VSELP CODEC BYPASS**Field of the Invention**

5 This invention relates to signal processing in a digital cellular system and more particularly, to a method of providing an automatic switching capability from a tandem to a single Vector Sum Excited Linear Prediction (VSELP) speech encoder/decoder configuration in a TDMA mobile-to-mobile connection.

10

Background of the Invention

Digital signal processor (DSPs) are used in digital mobile cellular radio systems to enable echo cancellation, speech encoder/decoder (codec) functions and channel encoder/decoder functions for TDMA channels. These digital signal processors perform in some installations echo cancellation on the switch side of the cellular infrastructure. Some equipment manufacturers provide for these functions on the cell site end of the cellular system. In both cases, the speech and channel encoder/decoder (codec) designs and implementations are made to compliance with Communications Technology Industry Association's (CTIA) Digital Cellular Interim Standard (IS-54) specification.

25

In a TDMA mobile-to-land connection, audio signals arriving at the digital signal processor from the land source is first subject to echo cancellation. The echo cancelled signal is then compressed into IS-54 VSELP signal format with a 8:1 ratio and the compressed signal is channel encoded and sent over the air to the mobile. VSELP signal arriving at the mobile is channel decoded and then used to reconstruct the original audio signal by the speech decoder. The entire speech encoding and decoding process introduces perceptible coding noise to the reconstructed speech signal. Audio signal travelling in the reverse direction (mobile to land) is subject to the same encoding

30

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and decoding processes but with no echo cancellation by the digital signal processors.

A TDMA mobile-to-mobile connection is realized basically by connecting two TDMA mobile-to-land calls back to back between two digital signal processors. Thus, an audio signal travelling in either direction is subject to two speech encoding and decoding processes operating in tandem. Thus, the coding noise introduced at each end degrades the quality of voice signal received by each subscriber.

Accordingly, a requirement exist to reduce the amount of coding noise which is generated during mobile-to-mobile communication.

Summary of the Invention

With the design of the present invention, the digital signal processor is provided with the capability to automatically switch configuration such that two digital signal processors can automatically identify a TDMA mobile-to-mobile connection and bypass the speech encoding and decoding processes within the digital signal processors. The two digital signal processors are virtually connected at the channel codecs. Thus enhancing the end-to-end audio signal quality as well as improving system performance.

According to an aspect of the present invention, there is provided a digital cellular radio system for enabling digital mobile radios to communicate with each other and the public switched telephone network via radio cell sites and a mobile switching office, said digital cellular radio system having digital signal processor means for providing echo cancellation, speech encoding/decoding and channel encoding/decoding of audio signals, comprising:

a first digital signal processor for enabling echo cancellation, speech encoding/decoding and channel encoding/decoding of audio signals from a local digital mobile telephone;

a second digital signal processor for enabling echo cancellation, speech encoding/decoding and channel encoding/decoding of audio signals from a remote digital mobile telephone;

5 a message transmitter for transmitting in-band signalling information to a remote digital signal processor;

a message receiver for detecting in-band signalling information at a local digital signal processor;
10 and

a controller for monitoring the transmission of signalling information from said a remote message transmitter to a local message receiver, wherein when said local message receiver detects inband signalling
15 information from said remote message transmitter indicating that a digital mobile-to-mobile connection is established, said first and second digital signal processors can switch to a by-pass mode to by-pass the speech encoding/decoding and echo cancellation functions such that each digital
20 mobile radio communicate audio signal directly with each other in a VSELP format via said channel encoding/decoding function.

Brief description of the Figures

25 Figure 1 is a block diagram illustrating a mobile-to-mobile connection over two digital speech processors at the switch side of a network;

Figure 2 is a block diagram illustrating a mobile-to-mobile connection with the codec by-pass feature
30 activated according to an embodiment of the invention;

Figure 3 is a representation of a frame of 8-bit PCM samples with mobile-to-mobile protocol bit stealing according to an embodiment of the invention;

Figure 4 is a representation of a frame of VSELP
35 signal according to another embodiment of the invention;

Figure 5 is an illustration of the receiver state diagram;

Figure 6 is an illustration of the transmitter state diagram;

Figure 7 is a table showing the transmitter state machine output for the diagram of figure 6;

5 Figures 8a-8g are flow diagrams showing the operations of the controller, message receiver and transmitters;

Figures 8h and 8i are flow diagrams of the PCM and VSELP input handler;

10 Figure 9 is a diagram illustrating the schedule of inter-application communication for PCM and VSELP signal transfers;

Figure 10 is a table describing the speech decoder input information;

15 Figure 11 is a diagram illustrating the TDMA frame structure between the echo canceller and speech codec; and

20 Figure 12 is a block diagram illustrating the different signal paths and TDMA connections for mobile-to-mobile communication.

Detailed Description of the Preferred Embodiment

Referring to Figure 1, we have shown a block diagram illustrating a network connection between two
25 cellular subscribers. In this embodiment, the subscribers communicate over the Public Switched Telephone Network via separate telephone exchanges. However, in some instances, it is possible for two subscribers to communicate with each other via the same telephone exchange. For example, a
30 mobile telephone exchange such as Northern Telecom's DMS-MTX can be connected to as many as 250 cell sites. Thus, it is possible that within a small city, all cell sites are serviced by the same mobile exchange. Accordingly, a
35 subscribers that require a communication link to each other.

In Figure 1, a first subscriber 100 is communicating with a second subscriber 120 via a first cell site 110 and mobile telephone exchange 112 and a second cell site 121 and mobile telephone exchange 122. The first and second mobile telephone exchanges communicate with each other over the PSTN 130.

As indicated above, the Digital Signal Processors 113 and 123 can either be part of peripheral equipment connected to the switch or part of the cell site infrastructure. The digital signal processors provide the capability of voice transcoding from mu-law (or A-law PCM depending on which standard is being used) to VSELP (Vector Sum Excited Linear Prediction) and vice-versa. Multiple DS-1 carrier interface circuits are used to distribute voice and control messages to and from the cell sites via trunks 114 and 124.

Digital signal processors are generally comprised of multiple signal processors commercially available from a number of suppliers. One such processor is Motorola's 560001 DSP.

In a TDMA mobile-to-land connection, audio signals arriving at the digital signal processor from the land source, i.e. PSTN 130, is first subject to echo cancellation at echo canceller 115. The echo cancelled signal is then compressed at speech codec 116 into IS-54 VSELP signal format with a 8:1 ratio and the compressed signal is channel encoded at channel codec 117 and sent over the air to the mobile subscriber 100 via the radio unit or cell site 110. VSELP signal arriving at the mobile is channel decoded and then used to reconstruct the original audio signal by the speech decoder. The entire speech encoding and decoding process introduces perceptible coding noise to the reconstructed speech signal. Audio signal travelling in the reverse direction (mobile to land) is subject to the same encoding and decoding processes but with no echo cancellation by the digital signal processor. Echo cancellation is provided on the PSTN side of the

connection to eliminate the effects of delays introduced by the speech coding and TDMA transmission processes. The connection from the digital signal processor to the mobile is equivalent to a four wire connection with substantial
5 delays due to speech coding and TDMA transmission. The echo occurs on the network side and is therefore cancelled in the digital signal processor.

When a TDMA mobile-to-mobile connection such as shown in Figure 1 is realized, two TDMA mobile-to-land
10 calls are basically connected back to back between two digital signal processors on the switch side in this case. An audio signal travelling in either direction is subject to two speech encoding and decoding processes operating in tandem. Thus, the coding noise introduced at each end
15 degrades the quality of voice signal received by each subscriber.

The codec bypass feature of the present invention is designed for TDMA mobile-to-mobile communications realized with two bypass-capable digital signal processors
20 connected on the switch side. Here, we define connected on the switch side as meaning that the digital signal processor operations are done at the switch end instead of the cell site end of the cellular infrastructure. As indicated before, some cellular infrastructures have
25 digital signal processors connected at the base station end of the link such that echo cancellation, speech coding and channel coding is done at the cell site.

Codec bypass realization is based on determining that one digital signal processor is directly linked with
30 another (or itself) in a mobile-to-mobile connection. The bypass feature consists of two components: a digital signal processor communication protocol and speech codec bypass mechanism.

As will be illustrated with reference to Figure
35 2, the digital signal processor communication protocol is used to set up communication between two enhanced digital signal processors 210 and 211 in the same mobile-to-mobile

connection. Upon successful handshakes, each digital signal processor activates the bypass mechanism to transmit the mobile audio signal in VSELP format to the other digital signal processor, and speech codec bypass is completed. Note that broken line 212 is not a physical path, but represents a virtual or logical path between the two digital signal processors.

The communication protocol is active at all time to establish and maintain communication with the remote digital signal processor. In the embodiment of Figure 2, the local digital signal processor is indicated at reference numeral 210 and the remote digital signal processor at reference numeral 211. The communication process is done via inband signalling and is independent of the echo cancellation, speech encoding/decoding and channel encoding/decoding applications. The communication protocol operations are transparent to the system users in all TDMA connections: mobile-to-land and mobile-to-mobile.

As will be explained later in further detail, the protocol design consists of three functional modules: a message receiver, a controller, and a message transmitter. They are responsible for in-band signal detection, dialogue and by-pass control and in band signal transmission, respectively. Operations of the message receiver and the message transmitter are independent of each other. The message controller serves as a link between them to update the message transmitter state on message receiver outputs.

An outgoing signal 215 of a bypass-capable digital signal processor for a TDMA channel is transmitted to the switch at a rate of 64 Kbps in both PCM or codec bypass modes. The signal is composed of two types of information--local mobile user audio signal and in-band signalling information. Format of the user audio signal and in-band signal are switched/changed in different stages of the inter-processor communication process.

Local mobile audio signal is transferred to the remote mobile in either of two formats. In non-VSELP

bypass mode, the information is sent as a sequence of 8-bit PCM samples. In codec bypass mode, frames of VSELP signal, augmented to a 64 Kbps data stream, are sent.

Two types of protocol messages are defined.

- 5 Specifically, two messages of equal length are available for the PCM sample sequence from the speech decoder output 216 and one message is for the VSELP byte stream from the speech decoder input 217 (see Figure 2).

10 The first message defined for the PCM sequence is the digital signal processor identifier, and the second is the acknowledgment to a remote DSP identifier. By default, the local digital signal processor 210 transmits speech decoder output together with DSP identifiers in the reverse direction toward the switch. These messages are
15 transmitted at a rate of 400 bits per second on the 64 Kbps digital link. Due to limitations of channel bandwidth in PCM transmission, bit stealing is in place to realize inband signalling. Each PCM message bit is sent by replacing a single user audio signal bit from an 8-bit PCM
20 sample. This bit stealing scheme takes place at a regular interval. The bit location in a PCM byte and the bit stealing interval are selected to minimize the perceptual impact on the PCM signal at the receiver.

In bypass mode, each frame of 20 ms VSELP signal
25 is also transmitted at a rate of 64 kbps. The protocol prefixes the outgoing VSELP information, 159 bits for a 20 ms frame, with the VSELP message for VSELP signal identification. Note that the Table shown in Figure 10 shows the 159 bit frame plus 3 CRC bits for a total of 162
30 bits. Given that a frame of VSELP data occupies a fraction of the bandwidth provided by the digital channel, the protocol augments the VSELP byte stream with additional information pertinent to the VSELP frame such as VSELP check sum.

35 Figure 3 shows a frame of 8-bit PCM samples superimposed with PCM message information. Here, X represents a PCM information bit and O is a message bit.

In the figure, bit stealing takes place on every third PCM sample. However, during an actual call, PCM bit stealing would be done at 1 bit every 20 samples. This rate is of course dependent on the operational parameters of the system.

As will be defined later, Figure 4 illustrates the structure of a VSELP frame containing a VSELP message and VSELP signal.

A Receiver State Machine and a Transmitter State Machine govern the protocol operations. The receiver state machine has two states as shown in Figure 5 for PCM and VSELP inputs, respectively, from the switch. State transitions occur on a 20 ms frame basis. The system enters and stays in state R1 for 20 ms in the absence of a VSELP message at the beginning of the input frame. It enters and stays in state R2 for 20 ms immediately after a VSELP message is detected. Under normal TDMA mobile-to-land communication, the machine always operates in state R1. During codec bypass in a TDMA mobile-to-mobile call, it operates in state R2.

The transmitter state machine, shown in Figure 6, has four states--T1 through T4. Each state dictates the type and format of local mobile signal to the remote digital signal processor, if available. Each state also determines the type of messages to write to the output stream--DSP Identifier, DSP Acknowledgment, or VSELP message. State transition is prompted by the received remote DSP messages.

The table of Figure 7, shows the digital signal processor output definitions. Each state is characterized by the transmission of a single user signal format and protocol message type. A protocol message is always written to the output 216 (see Figure 2). State T1 is the system's initial and default operating state. In case of a loss of synchronization with the remote DSP message, the transmitter state machine returns to state T1 regardless of the current state. In state T1, the message transmitter

223 superimposes PCM message "DSP Identifier" on the output PCM sample sequence. This is so even in the absence of a remote bypass-capable digital signal processor. The protocol does not switch to state T2 until the presence of a remote digital signal processor 211 is confirmed by an incoming "DSP Identifier" or multiple "DSP Acknowledge" at receiver 214. The "DSP Acknowledge" message is sent by the transmitter in state T2 to acknowledge the receipt of the remote "DSP Identifier". The transmitter transmits the user signal in VSELP format in both states T3 and T4. The protocol switches to state T3 when a "DSP Acknowledge" to its own identity is received from the remote digital signal processor. The objective of this handshaking process is to ensure a sane two-way communication and smooth transition before establishing the connection in VSELP bypass mode. State T4 is the final state in which the TDMA mobile to mobile connection is in full duplex codec bypass mode. Although both states T3 and T4 specify VSELP signal transmission, state T4 is entered only when the input to the digital signal processor is also in VSELP format. A fifth state, not shown in Figure 6, is entered when special system messages are received. In this state, the speech decoder output thus proceeds unchanged to the echo canceller 225 and the PSTN 130.

State T1 is entered again whenever there is a removal of the special messaging or a loss of synchronization.

This provision is necessary in applications such as mobile activated DTMF tone generation where a DTMF tone is generated on the Speech Coder and available in PCM format only. This design also provides the switch with the capability to manually disable the codec bypass feature. Figures 8a to 8i are flowcharts representing the operating instructions of the transmitter and receiver state machines, message transmitters and receivers and the PCM and VSELP input handler. Figure 8a shows the controller flowchart. Since a state transition occurs on a 20 ms.

basis, the controller is called once every 20 ms. Figure 8b shows the receiver update flowchart as initiated by the controller. That is, the receiver state is set to R1 or R2 depending on whether a VSELP message is received. The transmitter state machine is updated through 4 separate states as shown in Figure 8c and 8d, where state T1 is the system's initial and default operating state. Figure 8e is the operations flowchart of the message transmitter 223 shown in Figure 2. The transmitter is called once every 20 ms. Each PCM message is transmitted over multiple 20 ms. frames of PCM samples. The VSELP signal is split up and written into the least significant part of the output buffer entries. The most significant part of the entries has a bit pattern resembling low amplitude PCM samples. This is done in order to reduce the perceptual impact when the VSELP signal is falsely received as PCM samples. The operations flowchart of the Message receiver 214 of Figure 2 is shown in Figure 8f and 8g. The message receiver is called once for every input sample. The beginning of an outgoing PCM or VSELP message is synchronized with the beginning of a 20 ms. frame by the message transmitter. Detection of a remote PCM or VSELP message therefore defines the beginning of the remote framing structure seen by local digital signal processor.

Figures 8h and 8i describe the routine used to handle linearized PCM samples or VSELP signal from the switch. The PCM and VSELP handler routine is designed to properly read the PCM or VSELP input data at different operating mode. The PCM and VSELP handler routine is done at the speech encoder input. Note that in Figure 8i, the half cycle raised cosine window is off by default. It is turned on at VSELP to PCM transition for the first complete PCM sample frame after the transition. The PCM samples are attenuated by the cosine window whose weight ranges from zero to unity such that a smooth transition becomes effective with zero initial state. The PCM input samples to this routine are in 16-bit linear format.

As indicated earlier, the protocol design consists of three functional modules: a message receiver 214, a controller 213, and a message transmitter 223. They are responsible for in-band signal detection, dialogue control and in band signal transmission, respectively. Operations of the message receiver and the message transmitter are independent of each other. The message controller serves as a link between them to update the message transmitter state on message receiver outputs.

10 The function of the message receiver 214 is to detect and identify in-band signalling information in the input from a remote digital signal processor 211. It operates on a sample by sample basis asynchronous to the local digital signal processor TDMA framing structure.

15 By default, the local digital signal processor 210 receives PCM input signals from the switch side and the message receiver 214 attempts to acquire synchronization with incoming protocol messages. During PCM signal reception, the message receiver 214 monitors the designated bit of each input byte. It is only after multiple DSP identifiers are received that the presence of a remote digital signal processor 211 and a clear digital connection is confirmed. Upon validating the DSP identifiers, the message receiver operations are in synchronization with the framing structure of the remote digital signal processor 211. The message receiver continues monitoring the input byte stream for new protocol messages. Remote digital signal processor to local digital signal processor codec bypass on virtual or logical path 212 is confirmed upon receiving VSELP message at the beginning of a remote incoming frame. Synchronization with the remote digital signal processor is lost when the message receiver fails to detect new PCM or VSELP messages in the input, and the message receiver returns to operate in the synchronization acquisition mode.

35 The controller 213 operates the transmitter and receiver state machines on message receiver outputs and

also on the presence of any special messages to determine the proper operating mode of the state machines.

The message transmitter 223 is responsible for writing the output buffer with the local mobile audio
5 signal and the protocol messages in the proper format. It superimposes the "DSP identifier" or "DSP Acknowledge" messages on the DSP PCM output sequence, or it constructs a VSELP output frame with VSELP message and information bytes. The table of Figure 7 shows the transmitter output
10 format and the corresponding message types for different transmitter states.

The message transmitter operation is driven by the controller 213. The operation is also in synchronization with the local TDMA framing structure. As
15 shown in Figure 3 and Figure 4, each message bit is written to well-defined locations in the 20 ms (160 bytes) output byte sequence. Each selected message is transmitted in full length. The transmitter does not write a new message to the output stream until the last bit of the current
20 message is sent.

The loose coupling between the message receiver and message transmitter of the protocol design has two advantages. First the message receiver does not have to be in synchronization with the local TDMA framing structure.
25 Due to the effects caused by transmission delay, a 20 ms frame from the remote digital signal processor is not necessarily synchronized to a local TDMA frame upon arrival. The protocol design allows the message receiver to lock onto the input message regardless of the local TDMA
30 timing. The second advantage is that data type traversing in opposite directions on the DSP/DSP digital link can be asymmetrical. The signal format need not be PCM/PCM or VSELP/VSELP. While the local digital signal processor may be transmitting the local mobile user information in VSELP
35 format, the remote digital signal processor may be responding with PCM samples due to.

Echo Canceller Application

During the non-bypass mode of the bypass-capable digital signal processor, the speech codec 224 sends the 160 samples every 20 ms to the echo canceller 225 directly
5 in 8-bit PCM format. The linear to PCM conversion operations are executed directly on the speech decoder output on the speech codec. The resulting PCM bytes are delivered to the echo canceller 225 from the speech codec and then written to the digital signal processor output 215
10 on the switch side for the designated TDMA channel without further signal processing on the echo canceller .

During codec bypass in the local digital signal processor 210 to remote digital signal processor 211 direction, the user audio signal data is taken directly
15 from the speech decoder input--channel decoder output-- 217 in the form of VSELP compressed signal, framed with VSELP messages. It is sent via the echo canceller 225 to the digital signal processor output. A total of 160 bytes--in either PCM or VSELP format--is received at the input/output
20 buffer of the echo canceller 225 for each TDMA voice channel every 20 ms.

The bypass-capable echo canceller software transmits the echo cancelled samples to the speech codec in a 16-bit linear format, in two bytes via the input/output
25 buffer. In addition, signalling information from the message receiver on the echo canceller is transmitted to the controller on the speech codec. This information includes the number of remote VSELP bytes in the input/output buffer frame, remote message type and remote
30 message error count.

The echo canceller 225 for a TDMA channel is skipped as soon as the presence of a remote digital signal processor 211 is confirmed by the message receiver 214. Also, the canceller is not required since no hybrid is in
35 the direct digital signal path. After a remote digital signal processor is confirmed, input samples to the echo canceller from the remote digital signal processor will

undergo PCM to linear conversion only. The resulting 16-bit linear samples are written to the echo canceller input/output buffer for the speech codec as if they were echo cancelled samples.

5 VSELP input bytes from the remote digital signal processor are processed differently. When an incoming 20 ms frame--160 bytes--of VSELP signal is confirmed by the message receiver 214, every validated VSELP byte from the remote digital signal processor 211 is directly written,
10 accompanied by a zero byte, to the input/output buffer for the corresponding speech codec.

 Thus, a total of 320 bytes are sent to the speech codec by the echo canceller every 20 ms via the same buffer. The signal is echo cancelled in the absence of a
15 remote digital signal processor. Otherwise, the signal is sent directly from the echo canceller to the input/output buffer for the speech codec.

Speech Codec Application

20 The controller and message transmitter on the Speech Codec are invoked once every 20 ms. The controller takes input from the message receiver in each input/output buffer and executes the state machine to determine the next transmitter state (see Figures 8a-8g). The message
25 transmitter serves as a slave to the controller and writes the 20 ms input/output buffer with the proper data and message for the echo canceller.

 Figure 9 shows an example of the schedule of the speech codec communication with the echo canceller and
30 channel coder. With reference to Figure 2 and 9, we note that after the VSELP signal transfer from channel codec 226 to speech codec 224 is completed, the speech decoder 224 and the message transmitter 223 are activated in this order. In the case of codec bypass, in the local digital
35 signal processor to remote digital signal processor direction, the decoder is not activated. The output of this process is loaded in time slot "X" to the input/output

buffer to be sent to the echo canceller within the same 20 ms TDMA frame (figure 9).

After the speech codec receives the input/output buffer from the echo canceller, the controller is activated to update the state machine based on new information from the message receiver. The speech encoder is invoked, if needed, to compress the linear input samples. The compressed speech signal is sent to the channel codec in time slot "x" in the next 20 ms frame.

Two types of data can be transferred from the speech codec to the echo canceller. This data can be the speech decoder output or the speech decoder input, depending on the state of the local message transmitter. In either case, 160 bytes are written to the input/output buffer for the echo canceller.

In the bypass-capable digital signal processor software design, the linear to 8-bit mu-law/A-law PCM conversion are activated for speech decoder output samples in non-VSELP bypass mode. The resulting PCM samples --sequence of 8-bit bytes-- are superimposed with a PCM message as illustrated in Figure 3.

During codec bypass, the message transmitter writes directly into the input/output buffer the speech decoder input in VSELP format. Each 20 ms frame of VSELP signal to the speech decoder input consists of 159 bits of compressed speech signal and 3 bits of CRC state information. This information is presented to the speech decoder input in 28 bytes in the order as shown in the table of Figure 10.

The message transmitter breaks up these 28 VSELP information bytes into 4-bit units and writes every unit into a separate input/output buffer entry with the most significant units first. Specifically, each 4-bit unit is written to the input/output byte starting at the second least significant bit or bit one "1" to prevent potential conflict with T1 signalling information on a T1 trunk between two digital signal processors in a mobile-to-mobile

call. The remaining most significant bits of each input/output buffer byte is filled with a fixed pattern such that the complete byte is seen as a mu-law/A-law PCM code of small magnitude. This is done to reduce the undesired perceptual effect when the VSELP signal is falsely recognized or received as PCM signal.

Thus, the input/output buffer contains the VSELP message bytes followed by 28X2 size VSELP information bytes. An additional check sum byte is appended to the information bytes. The remaining input/output buffer entries are also filled with the same fixed pattern for the same purpose.

Two types of data received from the remote digital signal processor are transferred - 16-bit linear sample sequence and VSELP byte stream.

Due to the effects of transmission delay, a frame of VSELP compressed signal from the remote digital signal processor may not coincide with the local 20-ms frame structure in a direct TDMA mobile-to-mobile connection.

As illustrated in Figure 11, the content of a local 20 ms frame of data from the echo canceller to the speech codec has the following combinations:

- all linear samples (frame i)
- linear samples followed by VSELP signal as in PCM to VSELP transition (frame j)
- VSELP signal from two adjacent 20 ms frames (frame k, see section C below)
- VSELP signal from one single 20 ms frame (frame k, see section C below)
- VSELP signal followed by linear samples as in VSELP to PCM transition (frame l).

As indicated earlier, the echo canceller sends to the speech codec signalling information in addition to the user speech signal. This signalling information includes a VSELP byte count in each 20 ms input/output buffer transfer. A count of zero indicates an all linear sample transfer and a non-zero count denotes the number of

valid VSELP byte available in the transfer. The content of each input/output buffer is read with special care in the presence of VSELP signal. Examples of PCM and VSELP signal transfer and management, implemented in the bypass-capable digital signal processor load are as follows:

A. All linear sample transfer

When the VSELP byte count is zero, the complete 20 ms frame of linear samples is processed by the speech encoder as usual. Remote 20 ms framing structure has no effect on the local encoding process.

B. Non-zero VSELP byte count following an all linear sample transfer

This combination signals a PCM to VSELP --non-VSELP to codec bypass-- transition. One of two actions are taken to reconstruct a frame of VSELP information for the channel encoder. The selection decision is based on completeness of VSELP information in each input/output buffer transfer.

If the relationship between the local and remote framing structure is such that all remote VSELP information for a 20 ms speech frame reproduction falls in a single input/output buffer transfer, the VSELP information is reformatted and sent to the channel codec (CC) directly without invoking the speech encoder. The reformatting process involves extracting and concatenating the 4-bit units, most significant units first, to reconstruct the 28 VSELP information bytes.

If the framing relationship is such that the remote VSELP information for each 20 ms speech frame crosses the boundary of two adjacent local frames, the VSELP information is available in two input/output buffer transfers. The VSELP information available in the current local frame is stored in memory to be combined with the remaining VSELP information available in the next transfer. After being copied to memory, this partial VSELP information in the input/output buffer is replaced by

linear samples of zero amplitude. The entire frame in the input/output buffer is then considered to contain all linear samples and delivered to the speech encoder to be compressed.

5 C. Consecutive frames with non-zero VSELP byte counts

During remote to local digital signal processor bypass, consecutive input/output buffer frames from the echo canceller to the speech codec are filled up with VSELP signal. The VSELP byte count equals its maximum and
10 remains constant until the local digital signal processor loses synchronization with the remote VSELP signal. During a VSELP to PCM --VSELP to non-VSELP bypass-- transition, the local 20 ms frame contains partly VSELP signal and partly PCM linear samples with the VSELP byte count less
15 than its maximum.

• STABLE codec BYPASS: ALL VSELP TRANSFER

If there is enough VSELP information for a 20 ms speech reproduction, the VSELP bytes are reformatted and sent. Otherwise the buffer contains two sets of partial VSELP
20 information from two adjacent 20 ms frames. In this case, a frame worth of VSELP information is reconstructed with the partial VSELP information stored in the memory from the previous input/output buffer transfer and the first set of VSELP information available in the current input/output
25 buffer transfer. The reconstructed VSELP information is reformatted and sent to the channel codec. The memory is then updated with the second set of VSELP information to be used in the next frame.

30 VSELP SYNCHRONIZATION LOSS: PARTIAL VSELP TRANSFER

If there was enough VSELP information for a 20 ms speech reproduction in the previous input/output buffer transfer, the entire input/output buffer transfer is processed as all linear samples by the speech encoder. If
35 there is partial VSELP information stored in the memory, it should be combined with the partial VSELP information in

the current frame reconstruct a frame worth of VSELP information as in the "All VSELP Transfer" case above.

Thus, the speech encoder is skipped whenever there is enough VSELP information for a 20 ms speech frame to reconstruction. Otherwise, all linear samples from the echo canceller are processed by the speech encoder. In either case, the speech codec presents to the channel codec the VSELP compressed information in the same format. Before the speech encoder/decoder is reactivated, the coder state is reset. This ensures that the coder will not start from an unknown state. After the transition from bypass to non-bypass, a smoothing cosine weighting function is applied to the first PCM frame arriving from the remote processor to suppress any transition noise.

Cyclic Redundancy Check (CRC)

As shown in Figure 12, a mobile-to-mobile TDMA call consists of three signal paths. Two of the paths are over the air between the mobiles and the respective digital signal processors, and the third path is between the two digital signal processors. Mobile-to-mobile TDMA calls are subject to channel errors on these three paths, though the error rates are not the same.

According to the IS-54 specification, each VSELP speech decoder runs a state machine driven by CRC conditions of the channel between the mobile and the land terminals. In the presence of continuous CRC errors, the speech decoder replicates the Linear Prediction Coefficients (LPC) information and frame energy from the previously received CRC error free transmission. In the latter case, an attenuation factor is applied. The bypass-capable digital signal processor load is designed in such a way that the mobile-to-mobile feature is transparent to the mobiles. The principal of the design is to make the tandem links look like a single TDMA channel to the end users. In a mobile-to-mobile connection, the IS-54 specified state machine is activated once only by the receiving mobile in

response to a CRC error on path "L1" and/or path "L3". The text below details the operations involved in response to a CRC error.

Lets assume that a CRC error is detected on path
5 "L1" in the reverse direction by the channel decoder of
"S1". Instead of exercising the state machine to replicate
the LPC and frame energy as in a TDMA mobile-to-land
connection, "S1" running in codec bypass mode would pass
the 3-bit CRC state information together with the received
10 VSELP signal to channel encoder in "S2". In addition to
the defined IS-54 VSELP signal, the speech encoder also
sends to the channel encoder in "S2" the received CRC
status. A flag in the channel encoder is set for a non-
zero CRC state from "S1" and clear otherwise. The channel
15 encoder computes the CRC value for the received VSELP
signal if the flag is set.

Instead of transmitting the calculated CRC along
with the VSELP signal to mobile "M2", the channel encoder
sends the 1's complement of the calculated CRC together
20 with the VSELP signal for the first 6 consecutive CRC
failures. A CRC mismatch is effectively forced on mobile
"M2". In effect, a CRC error on path "L1" is seen by
mobile "M2" as a CRC error on path "L3" and acted upon
accordingly. The value of the 3-bit CRC state information
25 received from "S1" by the speech encoder in "S2" is
immaterial and is discarded after.

Transmission errors on path "L2" during codec
bypass is monitored with a VSELP check-sum measure. During
codec bypass, a VSELP check-sum is calculated on the
30 outgoing 3-bit CRC state information and the 12 most
perceptually significant VSELP bits by the message
transmitter. The check-sum figure is transmitted to the
remote digital signal processor in a VSELP frame. Upon
receiving a frame of VSELP information, the remote digital
35 signal processor calculates a new VSELP check-sum on the
received 3-bit CRC state information and the received VSELP
bits. The calculated VSELP check-sum is compared to the

received VSELP check-sum of the same frame. If the two check-sums are different, a "CRC error" on path "L2" is detected and the remote channel encoder is signalled as in the previous paragraph.

5 Only one state machine for VSELP signal replication is activated in each end-to-end TDMA mobile-to-mobile connection. Continuity of state machine operation for signal replication is ensured. In the case with CRC errors present on more than one paths, the reconstructed
10 signal frame energy is attenuated gradually as specified in IS-54 till total muting. If two independent state machines are activated in response to the consecutive or simultaneous CRC errors, fluctuation in the reconstructed signal frame energy will be observed.

15 The CRC computed is sent without modifications on the seventh or subsequent consecutive CRC failure. Instead, the frame energy 'R0' is set to zero to force a complete muting of the mobile audio signal on mobile 'M2'.

WHAT IS CLAIMED:

1. A digital cellular radio system for enabling digital mobile radios to communicate with each other and the public switched telephone network via radio cell sites and a mobile switching office, said digital cellular radio system having digital signal processor means for providing echo cancellation, speech encoding/decoding and channel encoding/decoding of audio signals, comprising:
 - a first digital signal processor for enabling echo cancellation, speech encoding/decoding and channel encoding/decoding of audio signals from a local digital mobile telephone;
 - a second digital signal processor for enabling echo cancellation, speech encoding/decoding and channel encoding/decoding of audio signals from a remote digital mobile telephone;
 - a message transmitter for transmitting in-band signalling information to a remote digital signal processor;
 - a message receiver for detecting in-band signalling information at a local digital signal processor; and
 - a controller for monitoring the transmission of signalling information from said a remote message transmitter to a local message receiver, wherein when said local message receiver detects inband signalling information from said remote message transmitter indicating that a digital mobile-to-mobile connection is established, said first and second digital signal processors can switch to a by-pass mode to by-pass the speech encoding/decoding and echo cancellation functions such that each digital mobile radio communicate audio signal directly with each other in a VSELP format via said channel encoding/decoding function.

2. A digital cellular system as defined in claim 1, wherein communication between said first and second digital signal processors comprises a mobile user audio signal and in-band signalling information.

5

3. A digital cellular system as defined in claim 2, wherein the audio signal and in-band signalling information is transmitted as a PCM sequence when in non-VSELP mode and transmitted in frames of VSELP signal when
10 in echo cancellation and speech codec by-pass mode.

4. A digital cellular system as defined in claim 3, wherein said PCM sequence comprises an 8-bit PCM sequence and said frames of VSELP signal comprises a VSELP
15 signal augmented to a 64 kbs data stream.

5. A digital cellular system as defined in claim 3, wherein PCM in-band signalling is achieved, by replacing a user's audio signal bit with a bit of a PCM message over
20 a number of audio signal frames.

6. A digital cellular system as defined in claim 5, wherein said PCM in-band signalling information comprises at least one of a digital signal processor
25 identifier message and a digital signal processor acknowledgment message.

7. A digital cellular system as defined in claim 6, wherein said user audio signal bit replacement is done
30 at a pre-selected interval small enough to reduce the time delay required to switch to a by-pass mode, but large enough to minimize the perceptual impact on the PCM signal at the receiver.

8. A digital cellular system as defined in claim 7, wherein said pre-selected interval is 1 bit every 20
35 samples.

9. A digital cellular system as defined in claim 8, wherein said DSP identifier and DSP acknowledgment messages are made up by replacing 16 user audio signal bits with message bits over a number of audio signal frames.

10. A digital signal processor as defined in claim 2, wherein the presence of a remote digital signal processor is confirmed by the receipt of incoming DSP identifiers at said message receiver.

11. A digital signal processor as defined in claim 10, wherein the speech decoding function is by-passed when DSP acknowledgment messages transmitted by a remote message transmitter are received repetitively at a local message receiver and the speech encoding function is by-passed when VSELP information is received at said local message receiver.

12. A digital signal processor as defined in claim 10, wherein the speech encoding/decoding functions are by-passed when VSELP information transmitted by a remote message transmitter is received at a local message receiver.

13. A digital signal processor as defined in claim 11, wherein PCM samples are scaled by a raised cosine window upon transition from VSELP by-pass to non-VSELP by-pass mode such that a smooth transition is effected.

14. A digital signal processor as defined in claim 13, wherein the speech encoding/decoding functions are reset upon transition from VSELP by-pass to non-VSELP by-pass mode such that a smooth transition is effected.

15. A digital signal processor as defined in claim 11, wherein by-pass mode can be terminated by

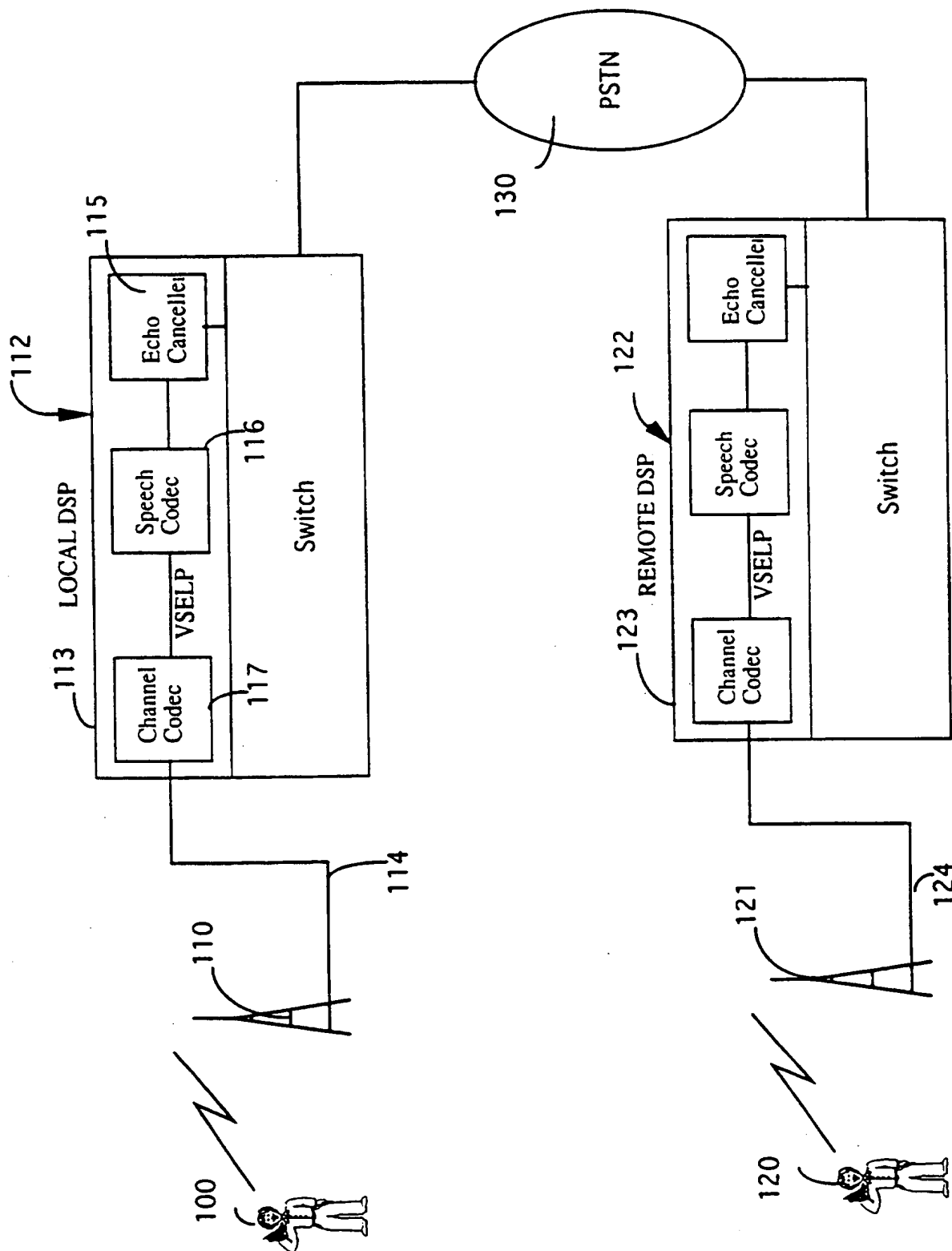
instructing the controller to deactivate the message transmitter.

5 16. A digital cellular system as defined in claim 4, wherein each frame of VSELP signal comprises a VSELP message repeated for each frame for VSELP signal identification, VSELP encoded user information, a checksum and a fixed pattern of weak PCM samples.

10 17. A digital cellular system as defined in claim 16, wherein said VSELP encoded user information is written into the least significant entries of an input/output buffer.

15 18. A digital cellular system as defined in claim 3, wherein a remote digital mobile telephone can be alerted of the occurrence of a CRC error at said first DSP from a signal arriving from said local digital mobile telephone, by sending said VSELP signal with CRC state information to
20 said second digital signal processor and subsequently sending said VSELP signal with a 1's complement of the calculated CRC to said remote digital mobile telephone for a first number of consecutive CRC failures, thus alerting said remote digital mobile telephone of a CRC error.

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Prior Art

Figure 1

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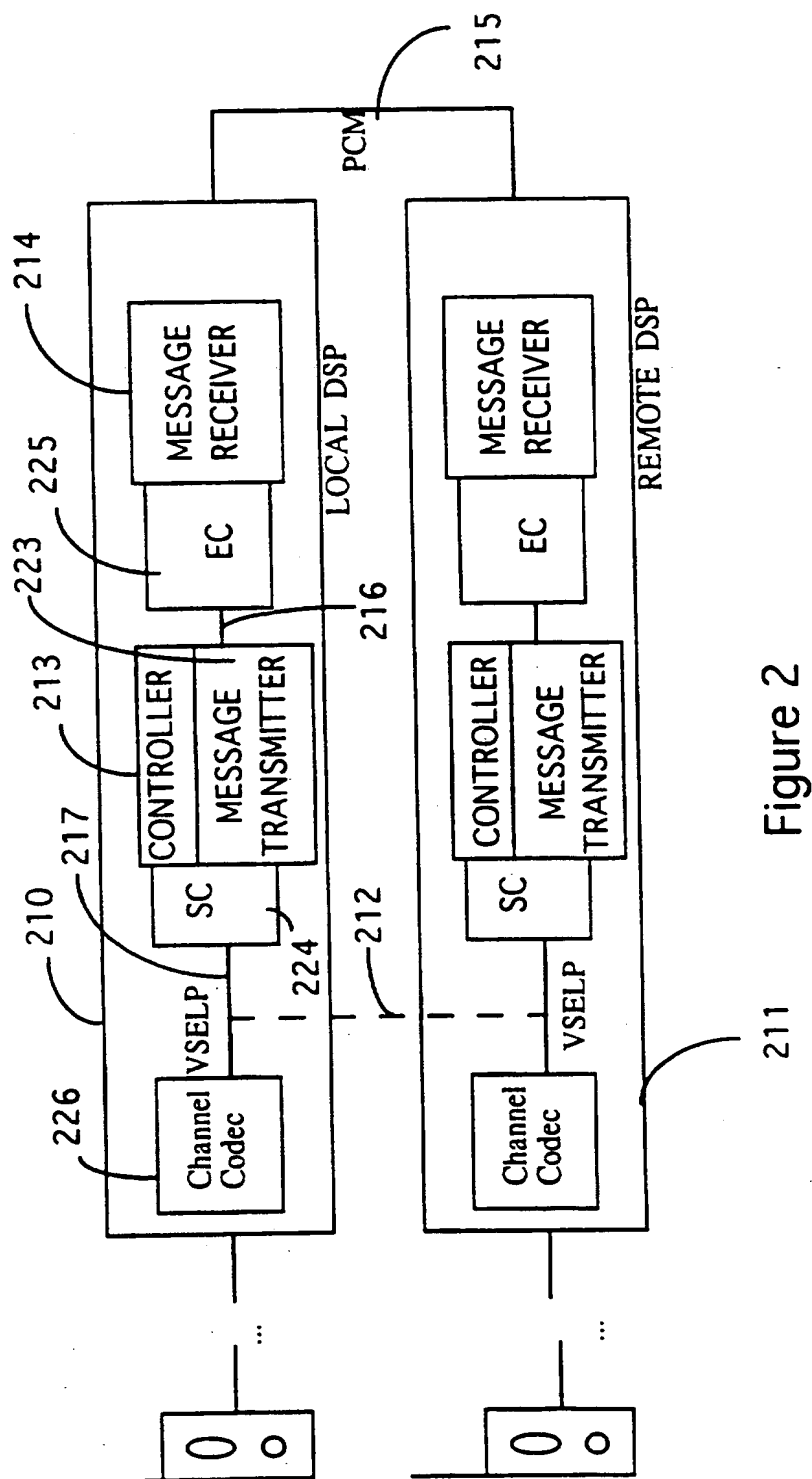


Figure 2

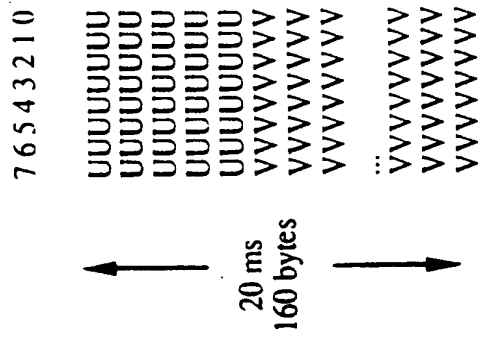


Figure 4

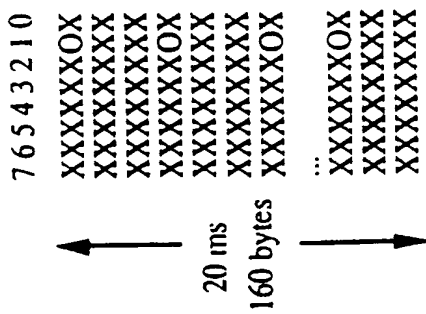


Figure 3

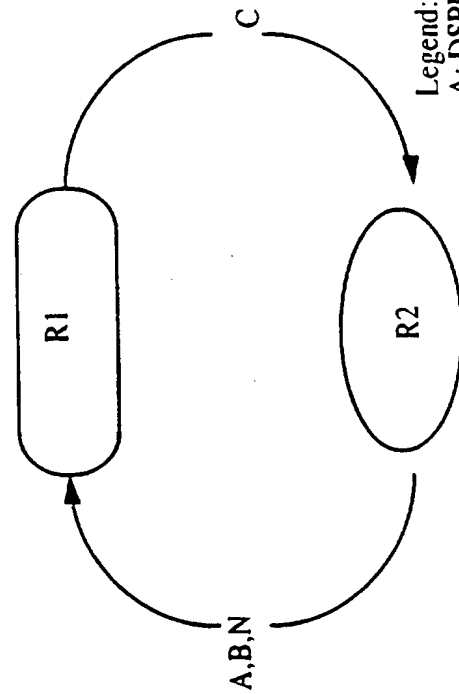


Figure 5

Legend:
A: DSPM Identifier
B: DSPM Acknowledge
C: VSELP message

N: No message

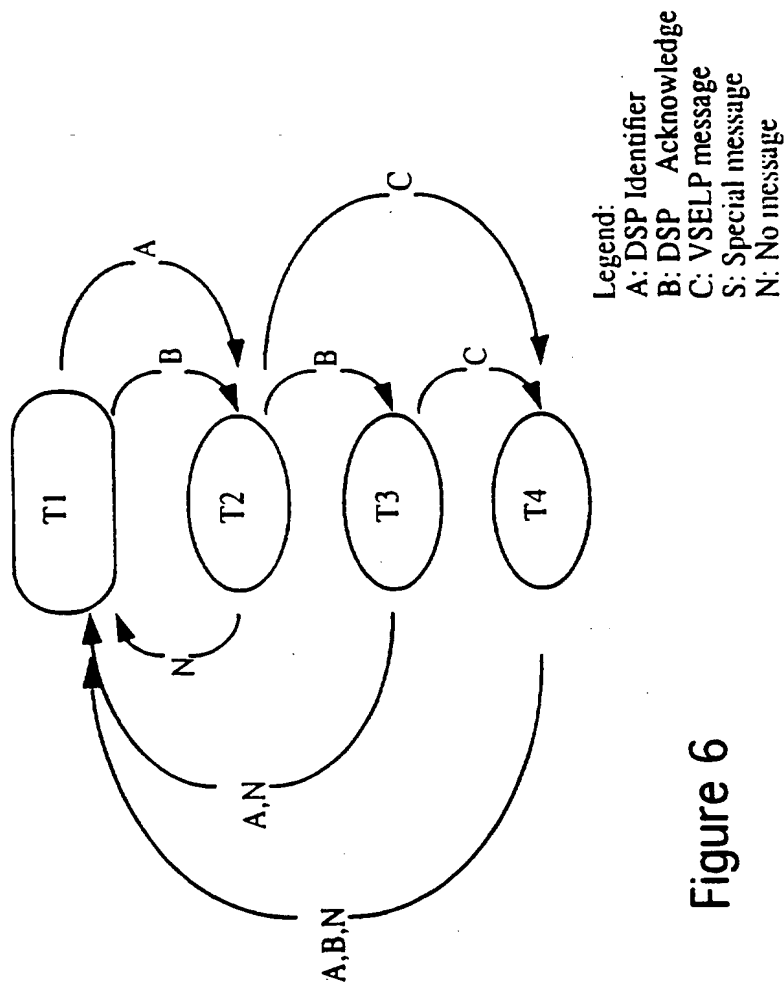


Figure 6

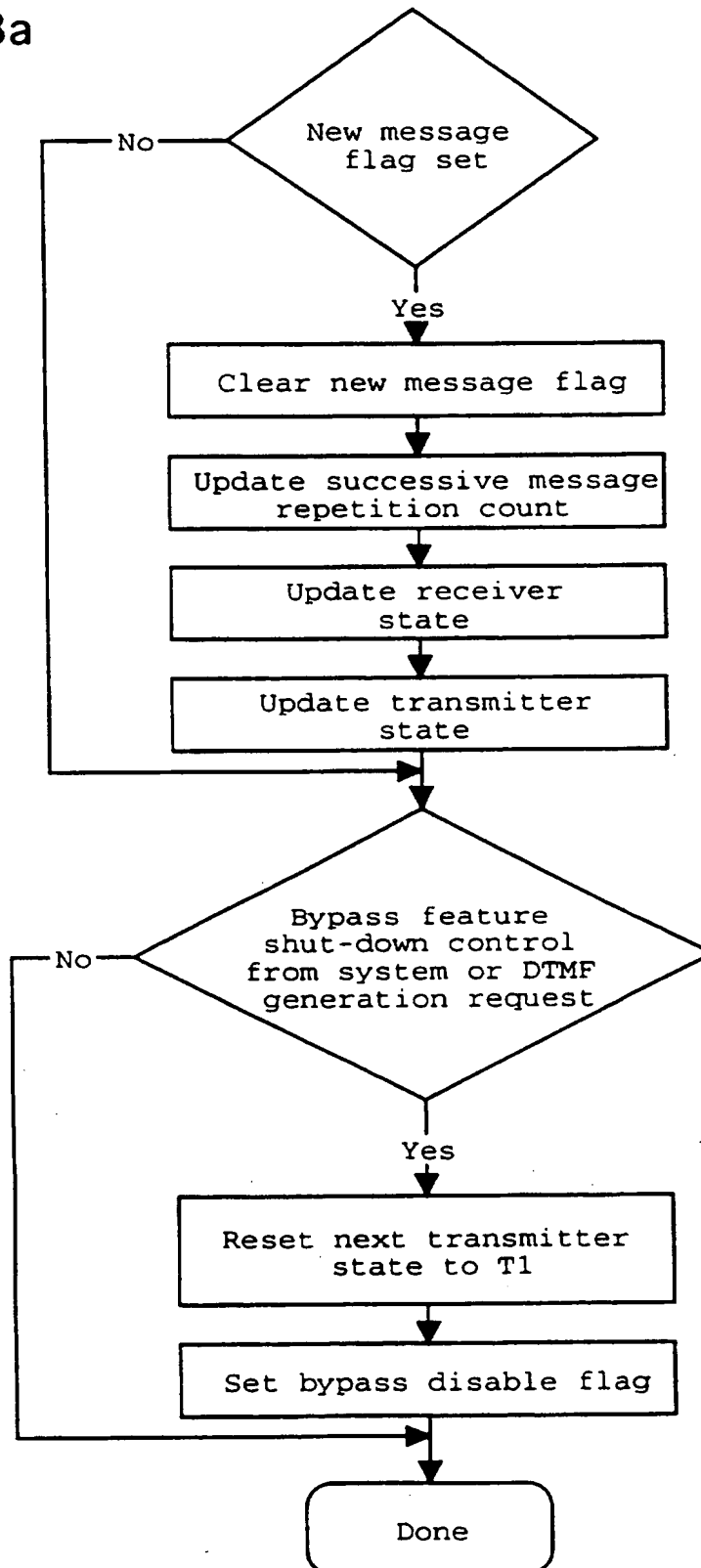
<u>Transmitter State</u>	<u>Output Format</u>	<u>Message to Transmit</u>
T1	PCM	"A" : DSP identifier
T2	PCM	"B" : DSP acknowledgment
T3	VSELP	"C" : VSELP
T4	VSELP	"C" : VSELP

Figure 7

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Controller flowchart

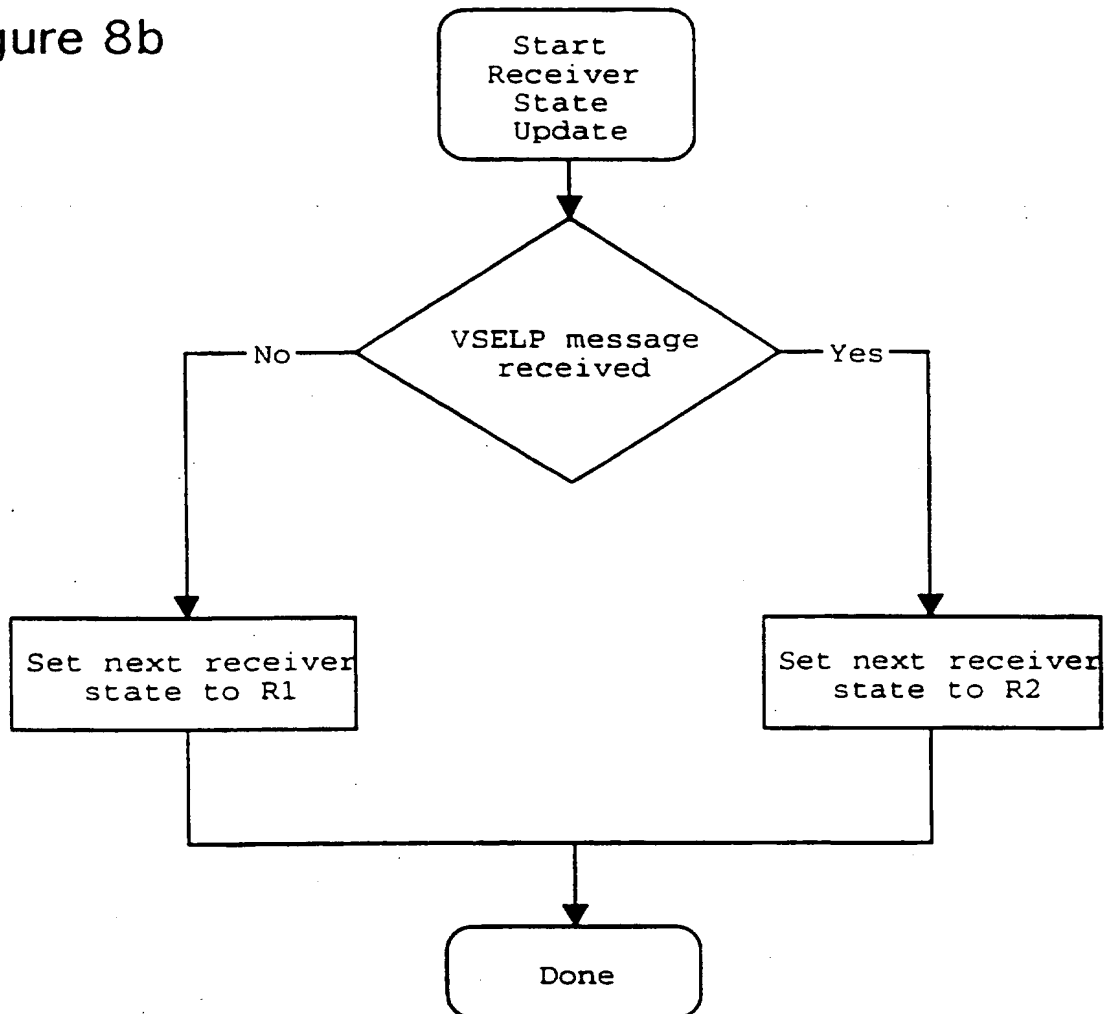
Figure 8a



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Controller: Receiver State Update

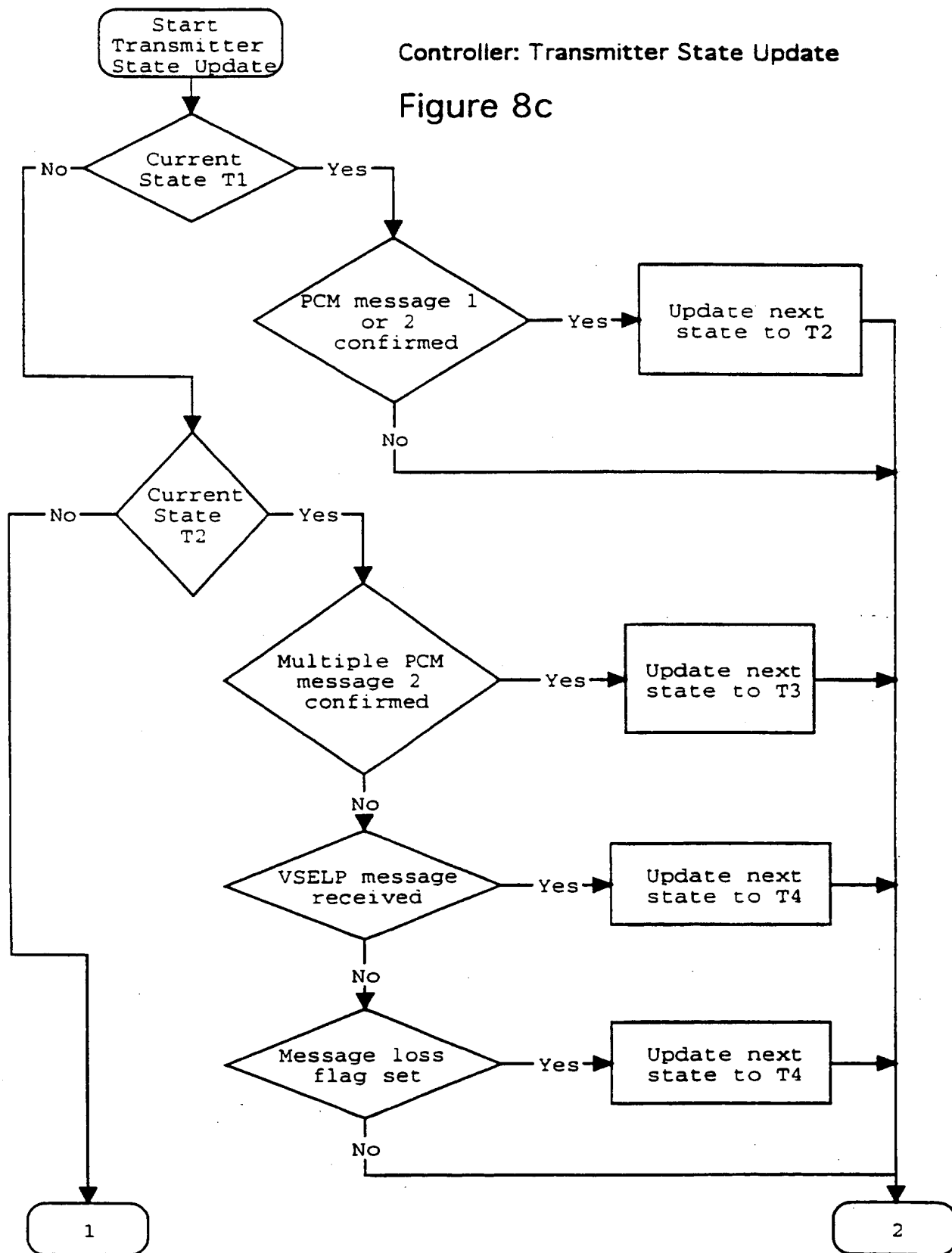
Figure 8b



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Controller: Transmitter State Update

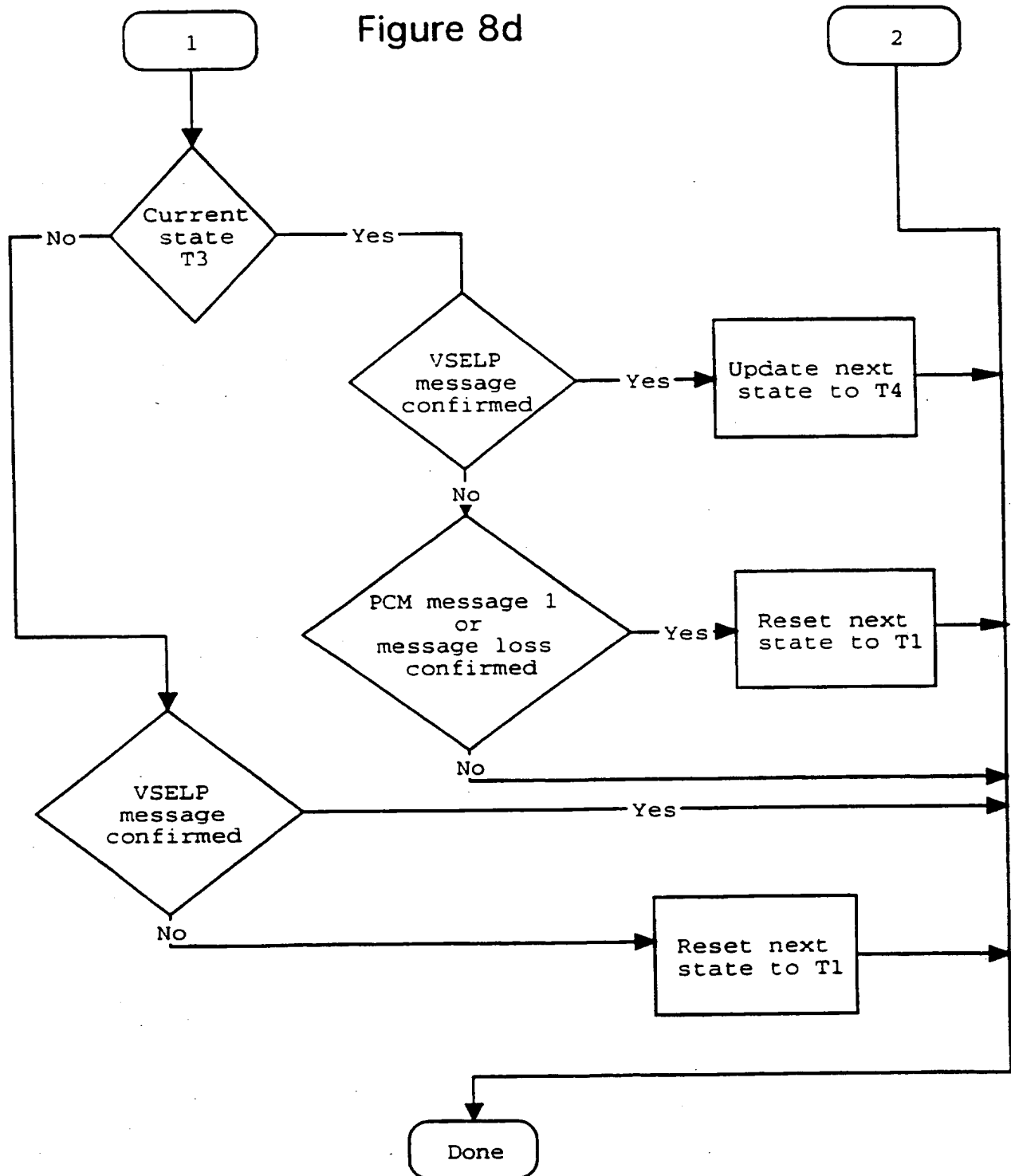
Figure 8c



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Controller: Transmitter
State Update (cont.)

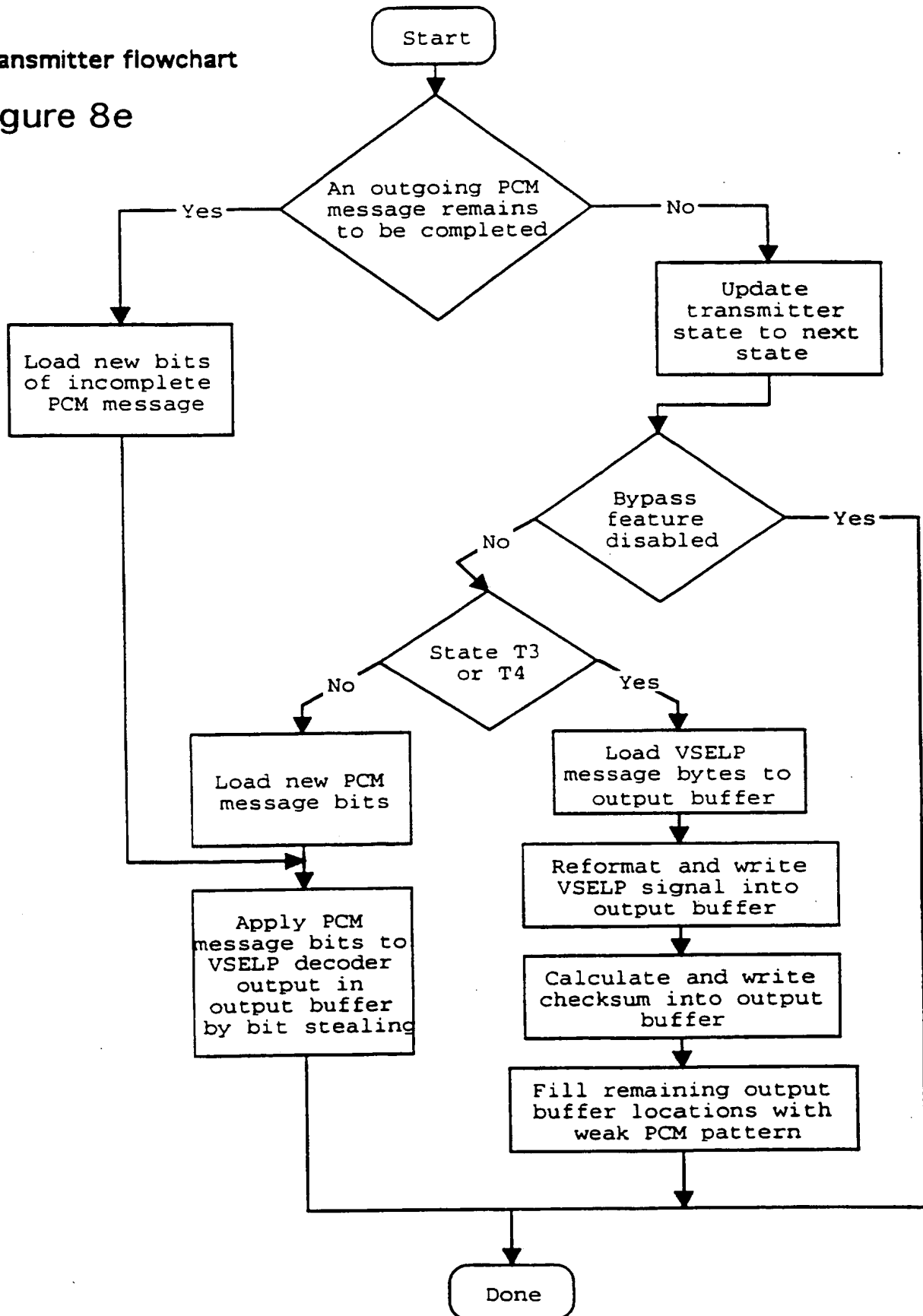
Figure 8d



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Transmitter flowchart

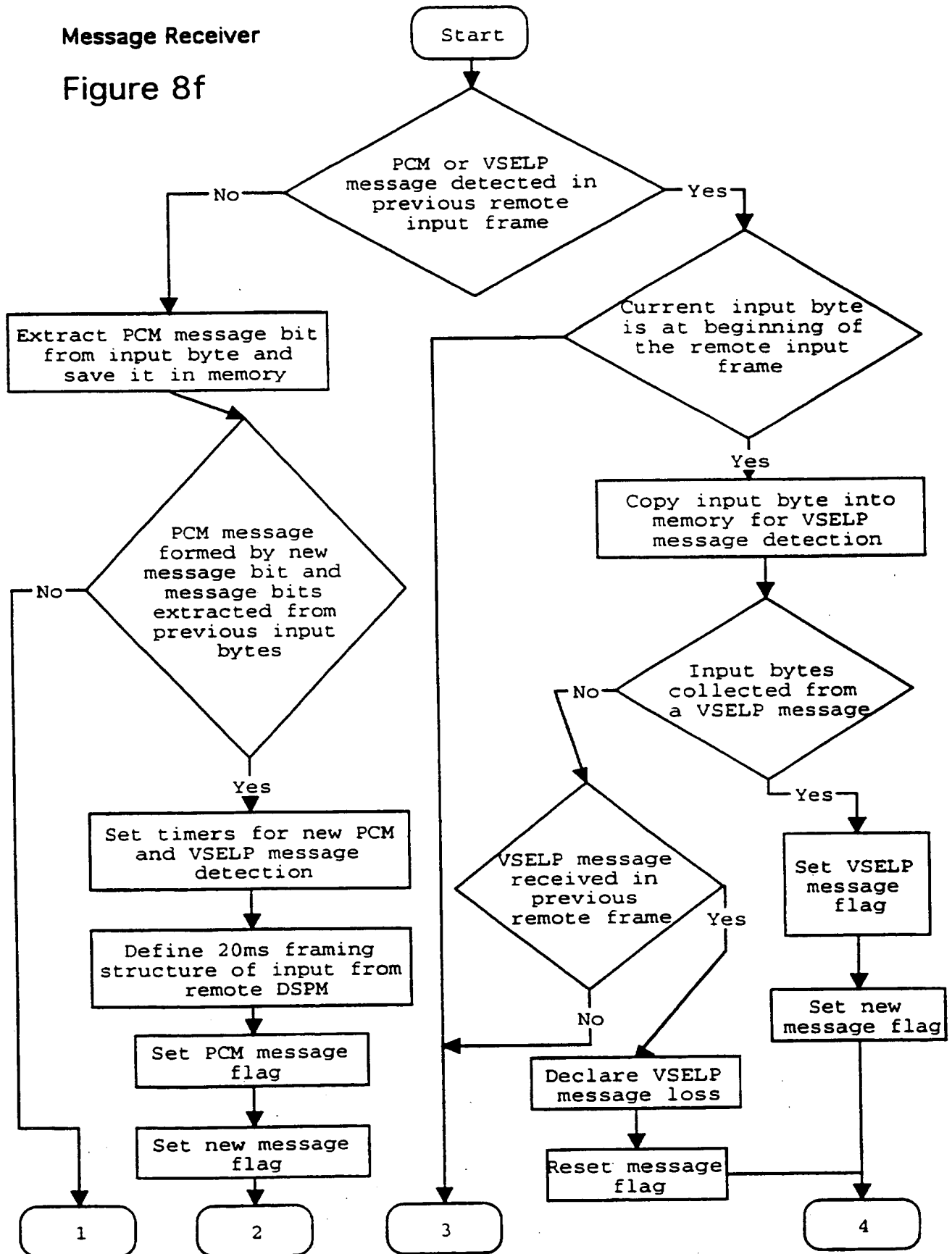
Figure 8e



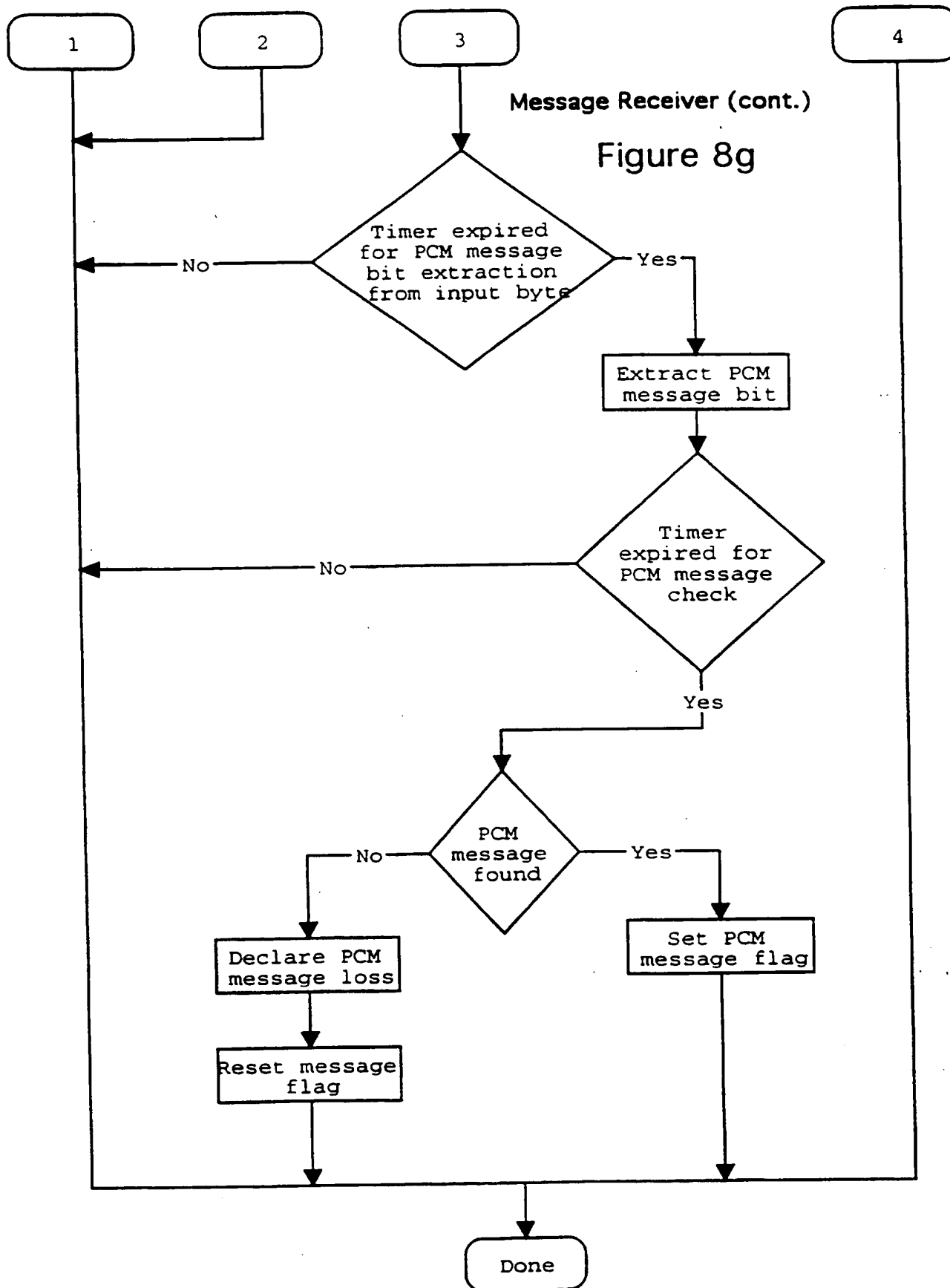
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Message Receiver

Figure 8f



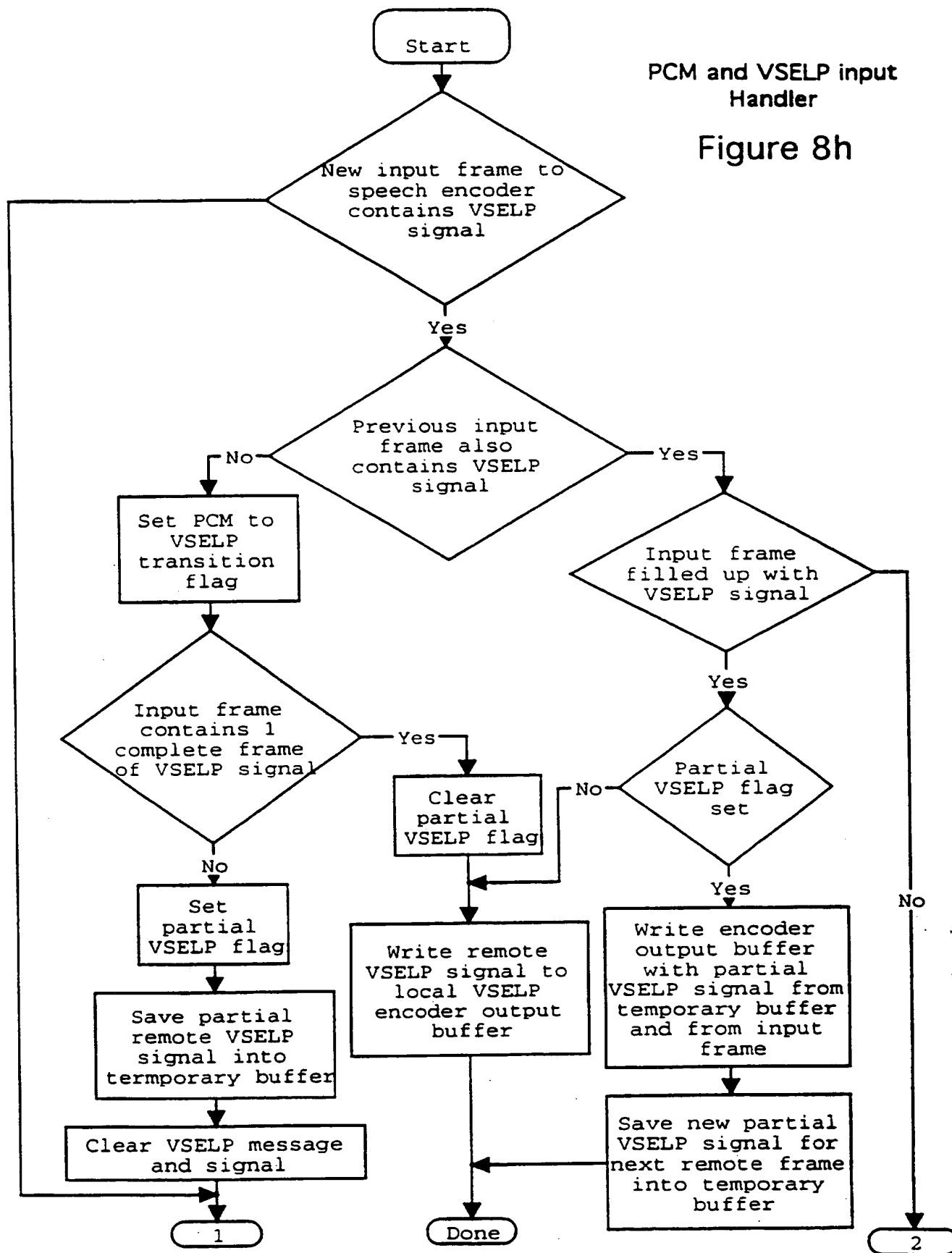
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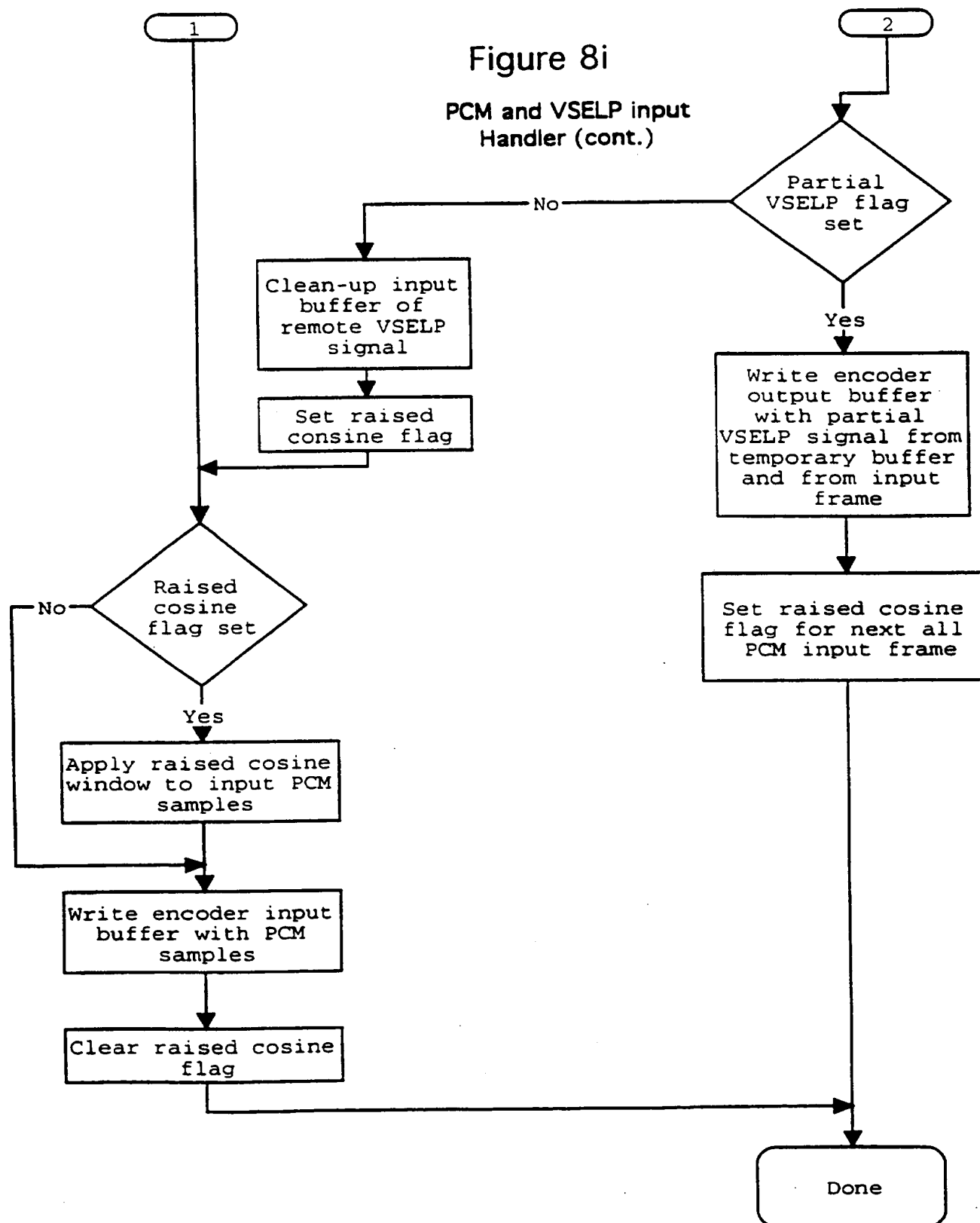
PCM and VSELP input
Handler

Figure 8h



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Figure 8i

PCM and VSELP input
Handler (cont.)

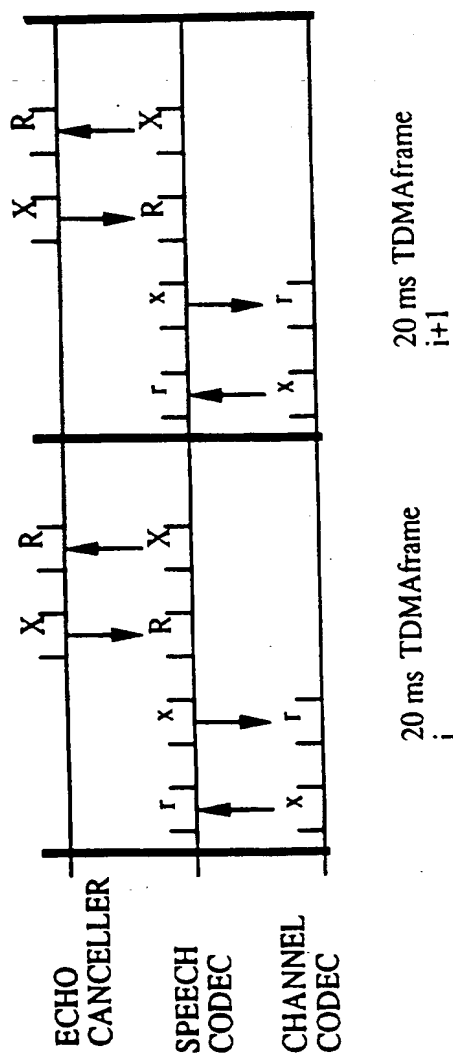


Figure 9

r : receive VSELP signal
 x : transmit VSELP signal
 R : receive PCM/VSELP signal
 X : transmit PCM/VSELP signal

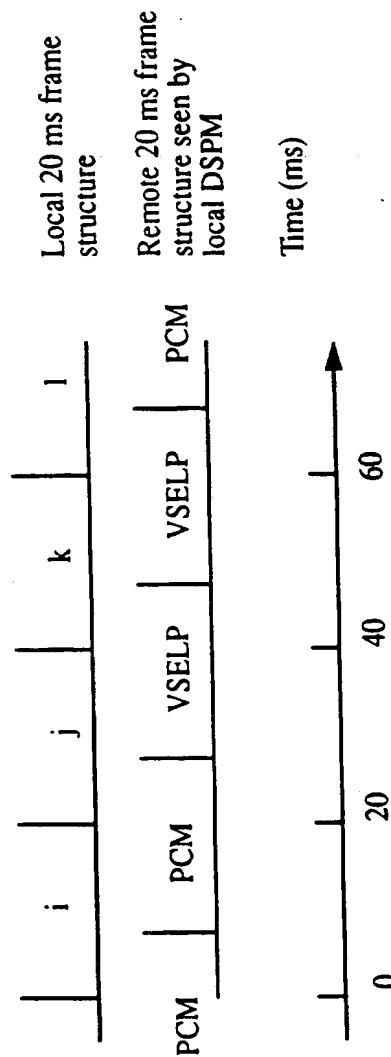


Figure 11

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VSELP	Parameter	Bits	Definitions
	STATE	3	CRC
	LPC1	6	1st reflection coefficient
	LPC2	5	2nd reflection coefficient
	LPC3	5	3rd reflection coefficient
	LPC4	4	4th reflection coefficient
	LPC5	4	5th reflection coefficient
	LPC6	3	6th reflection coefficient
	LPC7	3	7th reflection coefficient
	LPC8	3	8th reflection coefficient
	LPC9	3	9th reflection coefficient
	LPC10	2	10th reflection coefficient
	R0	5	frame energy
	LAG1	7	lag for 1st subframe
	CODE1_1	7	1st codebook code for 1st subframe
	CODE2_1	7	2nd codebook code for 1st subframe
	GSP0_1	8	excitation gains index for 1st subframe
	LAG2	7	lag for 2nd subframe
	CODE1_2	7	1st codebook code for 2nd subframe
	CODE2_2	7	2nd codebook code for 2nd subframe
	GSP0_2	8	excitation gains index for 2nd subframe
	LAG3	7	lag for 3rd subframe
	CODE1_3	7	1st codebook code for 3rd subframe
	CODE2_3	7	2nd codebook code for 3rd subframe
	GSP0_3	8	excitation gains index for 3rd subframe
	LAG4	7	lag for 4th subframe
	CODE1_4	7	1st codebook code for 4th subframe
	CODE2_4	7	2nd codebook code for 4th subframe
	GSP0_4	8	excitation gains index for 4th subframe

Figure 10

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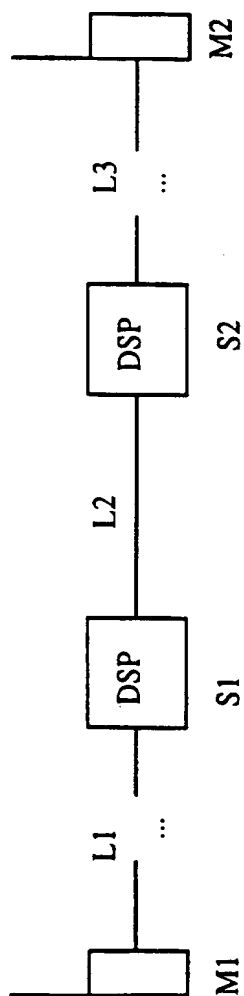


Figure 12

INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 95/00704

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04Q7/30

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 H04Q H04J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	-/--	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

15 March 1996

Date of mailing of the international search report

19.04.96

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 95/00704

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	VTC 1994. 'CREATING TOMORROW'S MOBILE SYSTEMS'. 1994 IEEE 44TH VEHICULAR TECHNOLOGY CONFERENCE (CAT. NO.94CH3438-9), PROCEEDINGS OF IEEE VEHICULAR TECHNOLOGY CONFERENCE (VTC), STOCKHOLM, SWEDEN, 8-10 JUNE 1994, ISBN 0-7803-1927-3, 1994, NEW YORK, NY, USA, IEEE, USA, pages 306-310 vol.1,	1,2,10, 12
A	YASUDA S ET AL 'Network functions for the application of multi-rate speech coding in digital cellular systems' see page 306, left column, line 9 - line 19 see page 306, left column, line 36 - line 40 see page 307, right column, line 25 - line 36 see page 308, left column, line 14 - page 309, left column, line 19 see page 309, right column, line 11 - line 18	3-9, 11-18
Y	--- EP,A,0 490 509 (NORTHERN TELECOM LIMITED) 17 June 1992 see claim 1 see column 3, line 18 - line 40	1,2,10, 12
A	--- VEHICULAR TECHNOLOGY SOCIETY 42ND VTS CONFERENCE, FRONTIERS OF TECHNOLOGY, FROM PIONEERS TO THE 21ST CENTURY, vol. 1, 10 - 13 May 1992 DENVER, COLORADO, pages 566-569, UEBAYASHI S. ET AL 'DEVELOPMENT OF TDMA CELLULAR BASE STATION EQUIPMENT' see paragraph 3.3 -----	1-18

information on patent family members

PCT/CA 95/00704

Form PCT/ISA/210 (patent family annex) (July 1992)

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